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RESEARCH MEMORANDUM

A PIVOTING-COWL-AND-SPIKE TECHNIQUE FOR EFFICIENT ANGLE-OF-ATTACK OPERATION OF SUPERSONIC INLETS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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A PIVOTING-COWL-AND-SPIKE TECHNIQUE FOR EFFICIENT ANGLE-OF-ATTACK OPERATION OF SUPERSONIC INLETS*

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SUMMARY

A technique to obtain efficient inlet performance over an angle-of-attack range at supersonic Mach numbers has been investigated. The system utilizes a pivoting spike and attached cowl-lip shell to maintain inlet alinement with the airstream at all attitudes. Two isentropic compression spikes of 35° and 39° total turning were examined with the pivoting system. Critical pressure recovery of the 35° compression spike inlet was essentially constant at 77 percent with only a 2-percent loss in mass-flow ratio and a maximum distortion value of 7 percent when the nacelle angle of attack was increased from 0° to 14° at the design free-stream Mach number of 3.0. Peak pressure recoveries of 80 and 86 percent were obtained at Mach 3.0 with the 35° and 39° compression spike inlets, respectively. Performance parameters at Mach numbers of 2.0 and 2.5 are also presented.

INTRODUCTION

Optimum performance over an angle-of-attack range is desirable for all types of aircraft and, in some cases, essential (for highly maneuverable aircraft). For high Mach numbers (greater than 2.0) a multicompression surface is usually required to give acceptable inlet performance, and the shock structure emanating from such a surface usually determines the cowl-lip location for optimum performance at zero angle of attack. Large decreases in internal performance have been experienced by conventional fixed-geometry inlet systems operating at angle of attack and may be attributed to (1) the shock system no longer being on-design but falling inside or outside the inlet or both and causing flow disturbances along with a reduction in capture mass flow and (2) asymmetric flow entering the inlet.

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*Title, Unclassified.

A number of techniques to alleviate the adverse flow conditions caused by conventional inlets operating at angle of attack have been made at low supersonic Mach numbers (refs. 1 to 7). All these techniques had some compromises in their designs, which resulted in unfavorable inlet flow conditions in some region of their angle-of-attack range. Higher design Mach numbers would probably amplify the penalties associated with these compromises.

A cowl-lip shell attached to a pivoting spike, the combination capable of alinement with the airstream direction, has the desirable characteristic of being on-design at all angles of attack. This report presents the results of an investigation in which this technique was incorporated in the design of a high-performance Mach number 3.0 inlet tested at Mach numbers of 2.0, 2.5, and 3.0, a Reynolds number of 2.5×10^6 per foot, and over an angle-of-attack range from 0° to 14°.

SYMBOLS

A_{in}	inlet capture area, 1.183 sq ft
A_{max}	maximum projected frontal area of model, 1.483 sq ft
A_x	area normal to flow direction in duct
A_3	diffuser-exit flow area, 0.961 sq ft
C_D	drag coefficient, D/q_0A_{max}
D	drag
M	Mach number
m_3/m_0	inlet mass-flow ratio, $\rho_3V_3A_3/\rho_0V_0A_{in}$
P	total pressure
$\overline{P}_3/P_0$	total-pressure recovery
$\frac{P_{3,max} - P_{3,min}}{\overline{P}_3}$	distortion parameter
q	dynamic pressure
V	velocity
x	distance along axis of symmetry

α angle of attack, deg

θ_l cowl-position parameter, angle between axis of symmetry and line from spike tip to cowl lip, deg

ρ density of air

Subscripts:

e external

max maximum

min minimum

0 conditions in free stream

3 conditions at diffuser exit

Superscript:

— area-weighted value

APPARATUS AND PROCEDURE

A photograph of the test model at angle of attack with the inlet alined with the free-stream direction is shown in figure 1. The test vehicle, a 16.46-inch-diameter, 102-inch-long model, had a movable exit plug to control the back pressure. Provisions for spike translation, as well as inlet pivoting, were also incorporated. Forces were measured with an internal strain-gage balance. A schematic drawing of the test model, with a cutaway view of the pivoting inlet, is shown in figure 2.

Two isentropic spikes were designed from the method of reference 8 to have focused compression at Mach 3.0 with total turning of 35° and 39°, corresponding to a $\theta_l = 23.65^\circ$ for both spikes. The cowl shell had a sharp-edged lip with 32° and 29° external and internal lip angles, respectively, (for both spikes) and a projected area 20 percent of the maximum frontal area. The cowl lip was attached to the spike with three aerodynamically contoured struts. The spike-cowl shell combination was remotely pivoted with an internally housed screw jack. All the pivoting components that had metal-to-metal contact were of spherical design to permit rotation about a fixed center with a minimum of air leakage. The spikes were designed with the capability of $1\frac{1}{2}$ inches of remotely

controlled translation in the constant-diameter portion of the centerbody immediately aft of the spike shoulder. This design permitted spike translation regardless of the spike-cowl shell angular position.

The bleed systems used with the 35° and 39° compression spike inlets are shown in detail in figure 3. The bleed mass flow was ducted out from the centerbody through two hollow struts and ejected to the airstream through two reverse-facing semiconical outlets located on the outer skin of the model (see fig. 1).

Total-pressure instrumentation was located at stations 1.8, 6.4, and 68 inches from the cowl lip. The total-pressure recovery was obtained from an area-weighted average of 48 total-pressure probes at station 68. The mass-flow ratio was calculated using the static pressure at station 68 and the assumption of isentropic flow to a choked area at the plug exit.

The geometry of the pivoting inlet components dictated the initial portion of the diffuser design. The internal area variation for optimum performance calculated from experimental data by the method of reference 9 at Mach numbers of 2.0, 2.5, and 3.0 with respective cowl-position parameters of 24.40°, 24.25°, and 23.65° is presented in figure 4.

The investigation was conducted in the Lewis 10- by 10-foot supersonic wind tunnel at free-stream Mach numbers of 2.0, 2.5, and 3.0 and a Reynolds number of 2.5×10^{6} per foot.

RESULTS AND DISCUSSION

Performance of the 35° compression spike inlet configuration at zero angle of attack over a Mach number range and at several cowl-position parameters is presented in figure 5. The Mach 3.0 on-design performance of the 35° compression inlet yielded a critical pressure recovery of 0.78, a drag coefficient of 0.15, and a distortion of 0.02. Only a small percentage of subcritical stability was noted at Mach 3.0. During operation in the unstable region, a static-pressure fluctuation as high as 65 percent of the free-stream total pressure was recorded at the compressor face. A bleed mass flow of approximately 5 percent of the inlet capture flow was removed from the spike surface at all the Mach numbers with the bleed system. Losses in total pressure through the diffuser at zero angle of attack near critical inlet operation are shown in figure 6. Eighty percent of the losses occurred in the initial 10 percent of the diffuser.

The performance of the inlet with pivoting cowl and spike as compared to the conventional fixed-geometry inlet is presented in figure 7

at a free-stream Mach number of 3.0 and a cowl-position parameter of 23.60°. The nacelle angle of attack could be increased from 0° to 14° with essentially no loss in critical pressure recovery (0.77) and with only a 0.02 loss in mass-flow ratio and a relatively slight increase in the distortion parameter (0.01 to 0.07). Losses of 0.11, 0.30, and 0.33 in critical pressure recovery, accompanied by respective losses of 0.01, 0.06, and 0.20 in mass-flow ratio, resulted when the fixed-geometry nonpivoted inlet was tested at angles of attack of 5°, 10°, and 14°.

The effect of adding 4° of external compression to the 35° spike resulted in marginally better performance, however, the peak pressure recovery was increased from 80 to 86 percent. Figure 8(a) shows the performance of the 39° compression inlet at zero angle of attack over a range of cowl-position parameters, and figure 8(b) shows the effect of pivoting the cowl and spike through an angle-of-attack range. The results of the 39° compression inlet with pivoting (fig. 8(b)) were similar to those with the 35° compression inlet, which substantiates the effectiveness of the pivoting technique at angle of attack.

Figure 9 is a summary plot depicting the effect of angle of attack on the critical inlet performance with and without inlet pivoting at a Mach number of 3.0. In all cases where inlet pivoting was employed, the unfavorable effects associated with a conventional fixed-geometry inlet operating at angle of attack were virtually eliminated. It thus appears that the sharp turn occasioned by the pivoted cowl and spike in the subsonic portion of the diffuser had relatively little effect on the performance of this type of inlet and that all the adverse effects of angle of attack produced by the supersonic diffuser can be eliminated by alining only a short portion of the nacelle with the free stream. Although drag data at angle of attack are not presented, the drag increment between the pivoted and nonpivoted configurations was a very small portion of the over-all nacelle drag and was within the accuracy of the balance measurements.

Total-pressure contours of the pivoted and nonpivoted 35° compression inlets at the diffuser exit for near critical operation over an angle-of-attack range are presented in figure 10. At all angles of attack, distortion was markedly reduced when the pivoting technique was employed. The largest degree of improvement in flow distortion along with elimination of any flow separation zones was noted at 10° and 14° angles of attack where distortions of 0.22 and 0.36 were reduced to 0.04 and 0.05, respectively, when inlet pivoting was employed.

Shock patterns at the inlet face at various Mach numbers and angles of attack with and without inlet pivoting are shown in the schlieren photographs in figure 11. Close examination of the shock structure at the design Mach number revealed the initial conical shock to be lying

slightly ahead of the coalescence of the weak shocks emanating from the isentropic surface. This shock orientation accounted for about 0.03 loss in mass-flow ratio when the inlet was operating on-design ($\theta_l = 23.65^\circ$).

SUMMARY OF RESULTS

A pivoting-cowl-and-spike technique for efficient angle-of-attack operation of supersonic inlets has been investigated with the following results at the design Mach number of 3.0:

1. There was essentially no loss in critical total-pressure recovery (0.77), only a 2-percent loss in mass-flow ratio, and a maximum distortion value of 0.07 when employing the pivoting 35° compression spike inlet over the model angle-of-attack range of 0° to 14°.

2. Peak pressure recoveries of 80 and 86 percent were obtained with the 35° and 39° compression spike inlets, respectively.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, July 16, 1958

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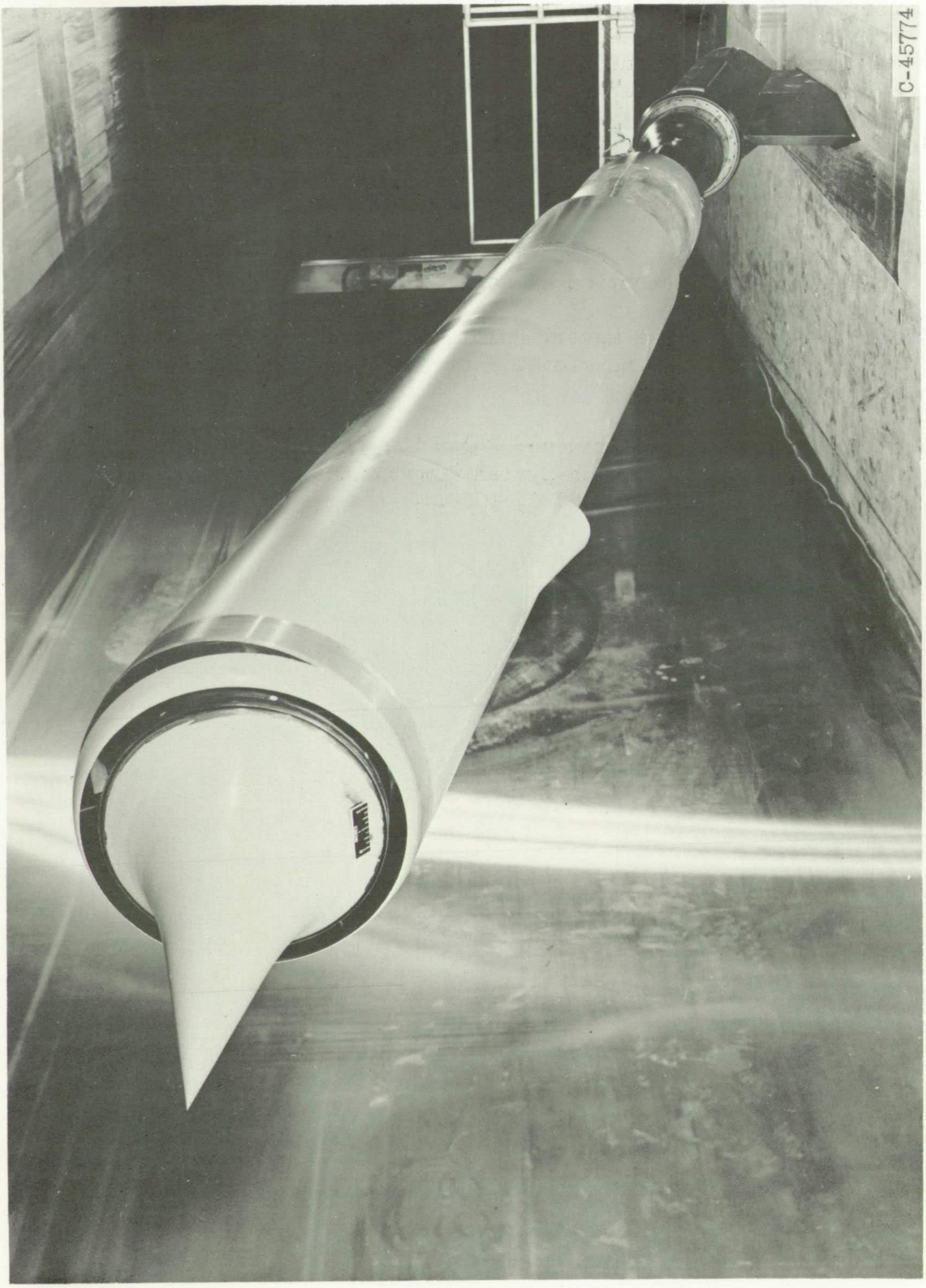
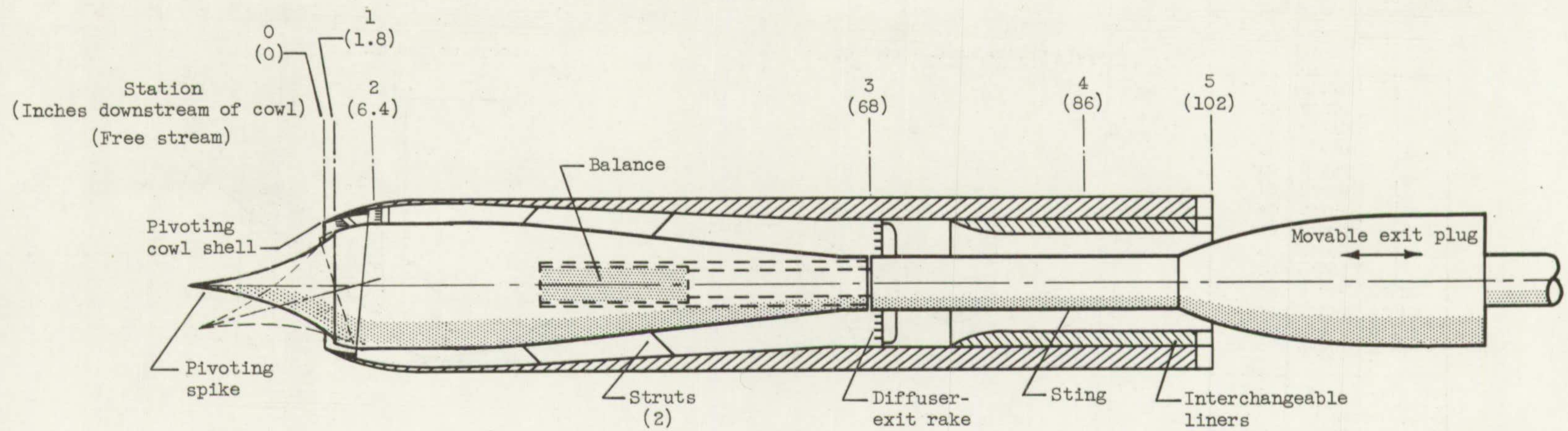
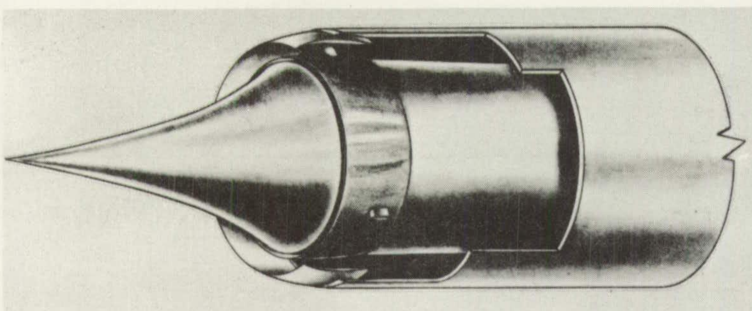


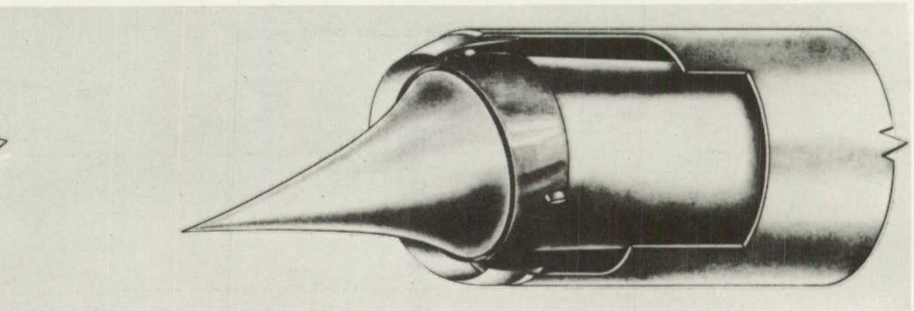
Figure 1. - Test model installed in 10- by 10-foot supersonic tunnel.



Schematic diagram of over-all test model



Inlet and model at
zero angle of attack



Inlet pivoted for angle-
of-attack operation

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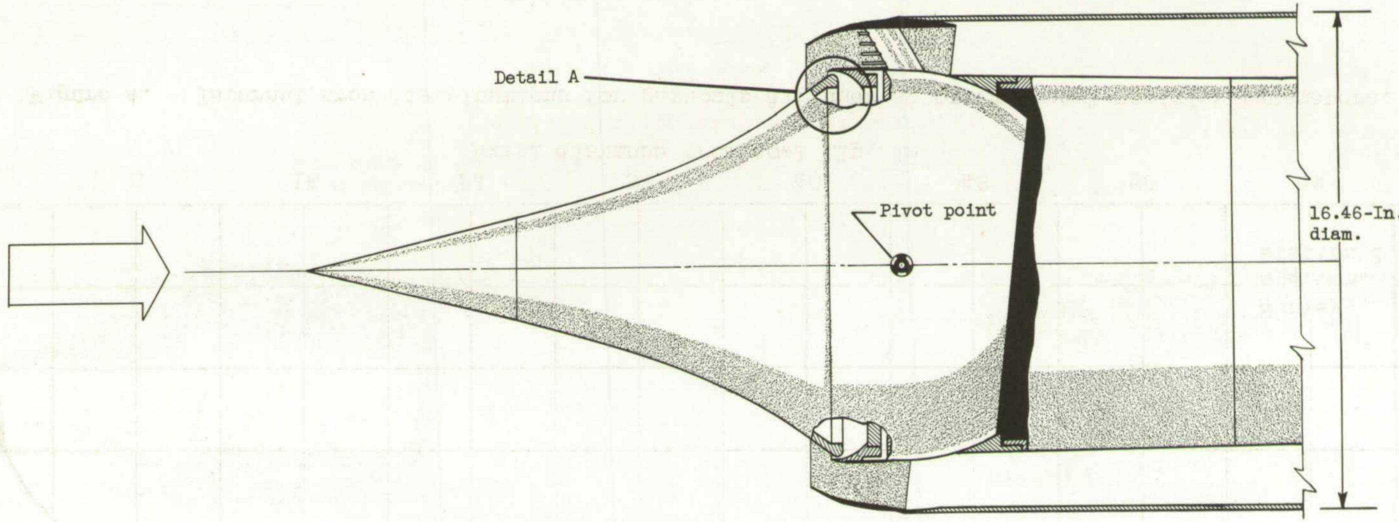
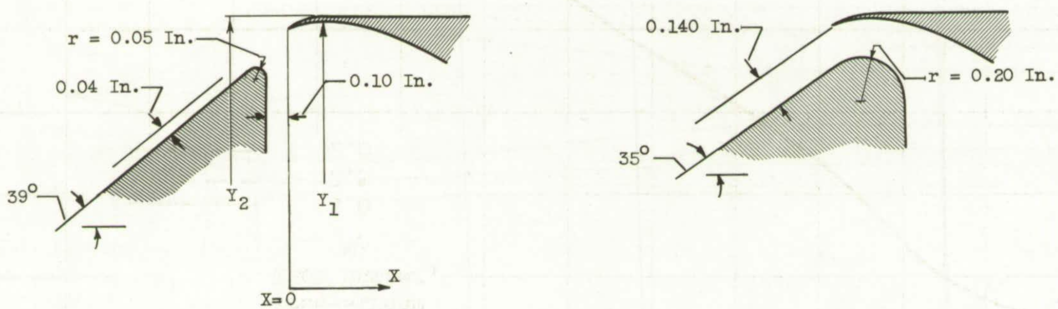
Cutaway of pivoting spike and cowl assembly

Figure 2. - Experimental apparatus.



Ram scoop coordinates for 35° and 39° bleeds, in.		
	Radii	
X	Y_1	Y_2
0	6.470	6.470
.05	6.483	6.499
.10	6.498	6.512
.15	6.504	6.520
.20	6.506	
.25	6.500	
.30	6.492	
.40	6.468	
.50	6.430	
.60	6.385	
.70	6.330	
.80	6.270	
.90	6.200	
1.00	6.130	



39° Spike compression bleed

35° Spike compression bleed

Detail A

CD-5963

Figure 3. - Illustration depicting boundary-layer bleed systems.

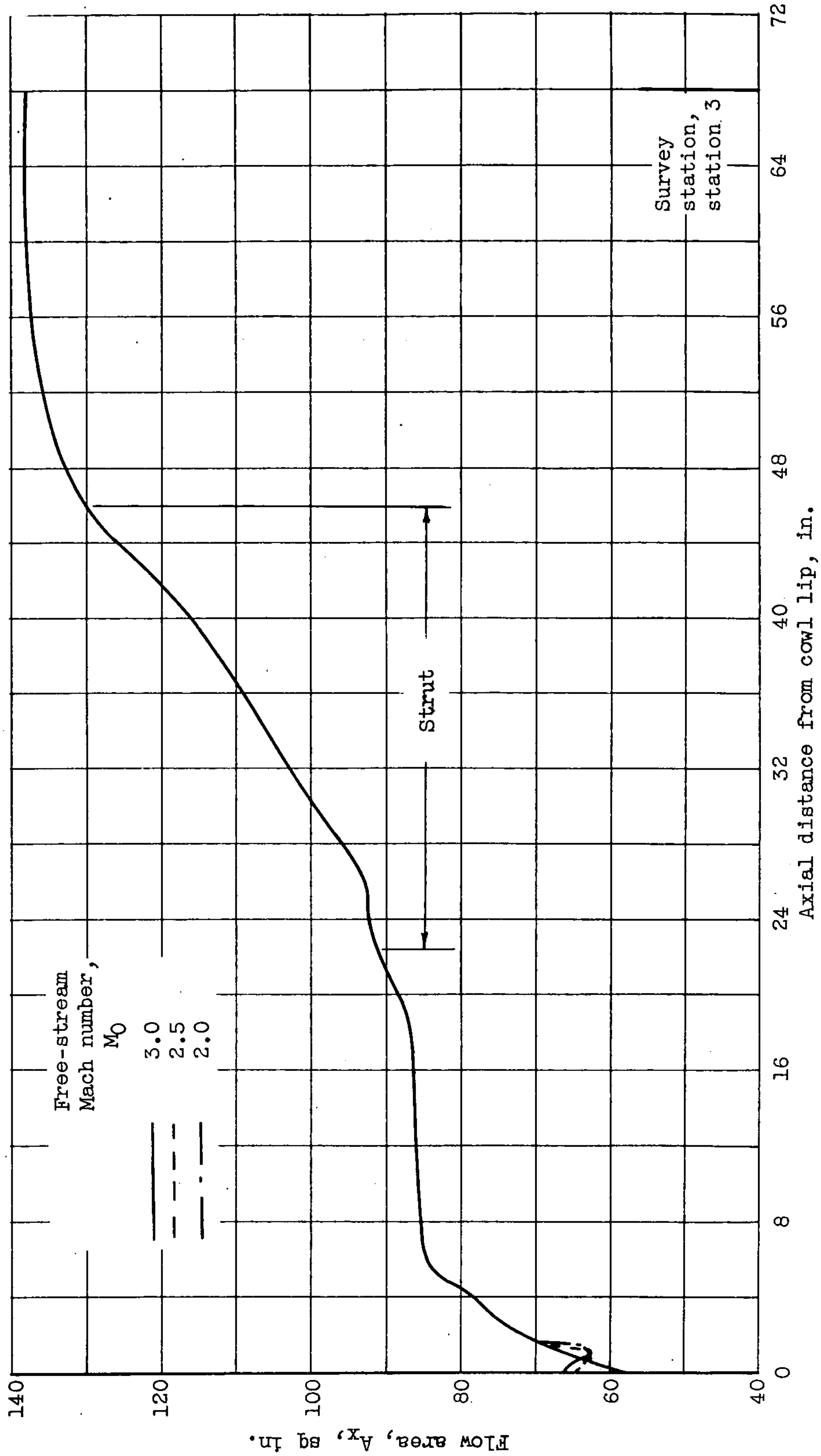


Figure 4. - Internal area distributions for subsonic diffuser at optimum cowl-position parameters.

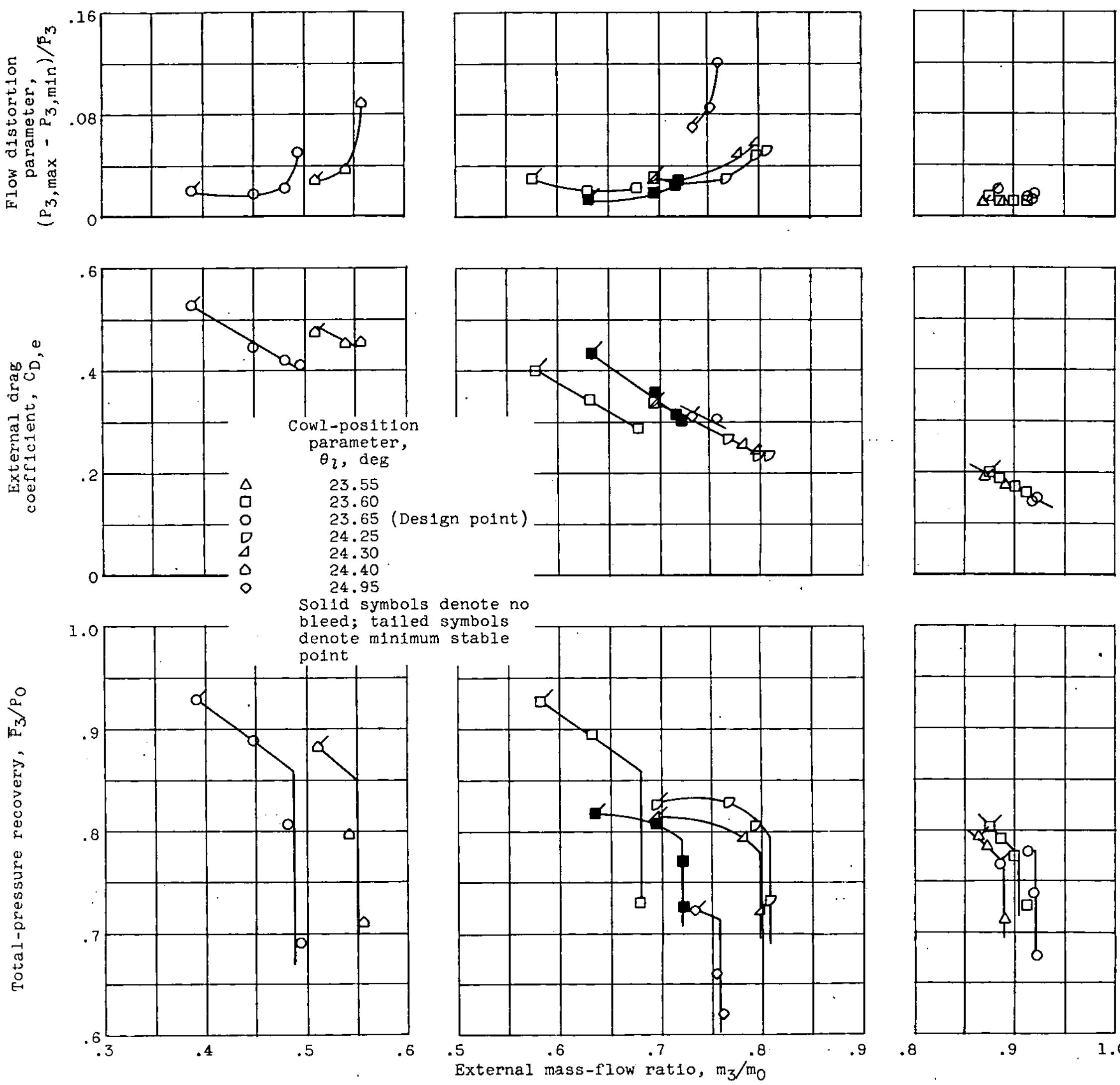


Figure 5. - Internal and external performance over a Mach number range of 35° compression spike inlet at zero angle of attack and various values of cowl-position parameter.

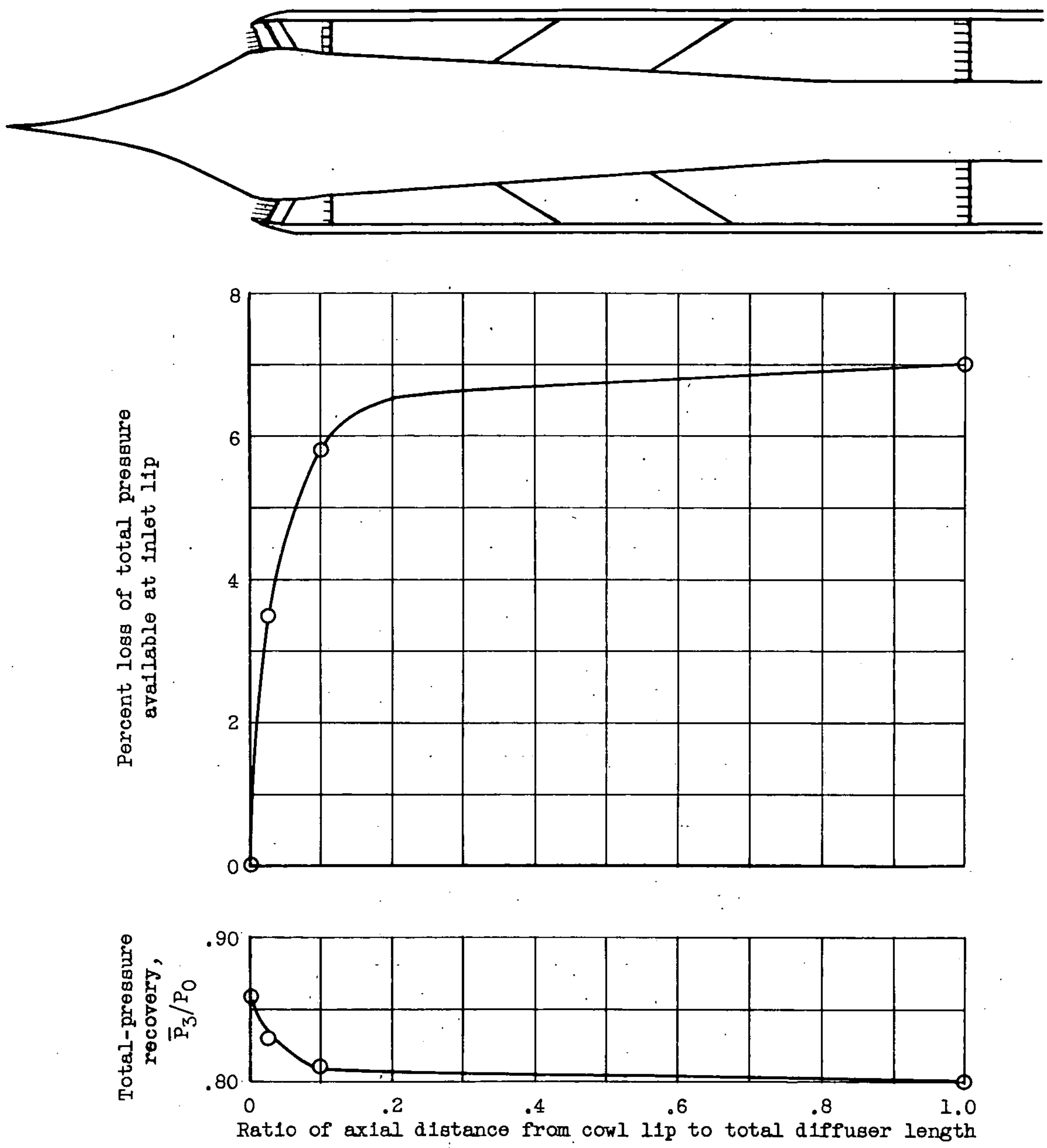


Figure 6. - Location of total-pressure losses in subsonic diffuser for near critical operation at zero angle of attack. Free-stream Mach number, 3.0; cowl-position parameter, 23.60°.

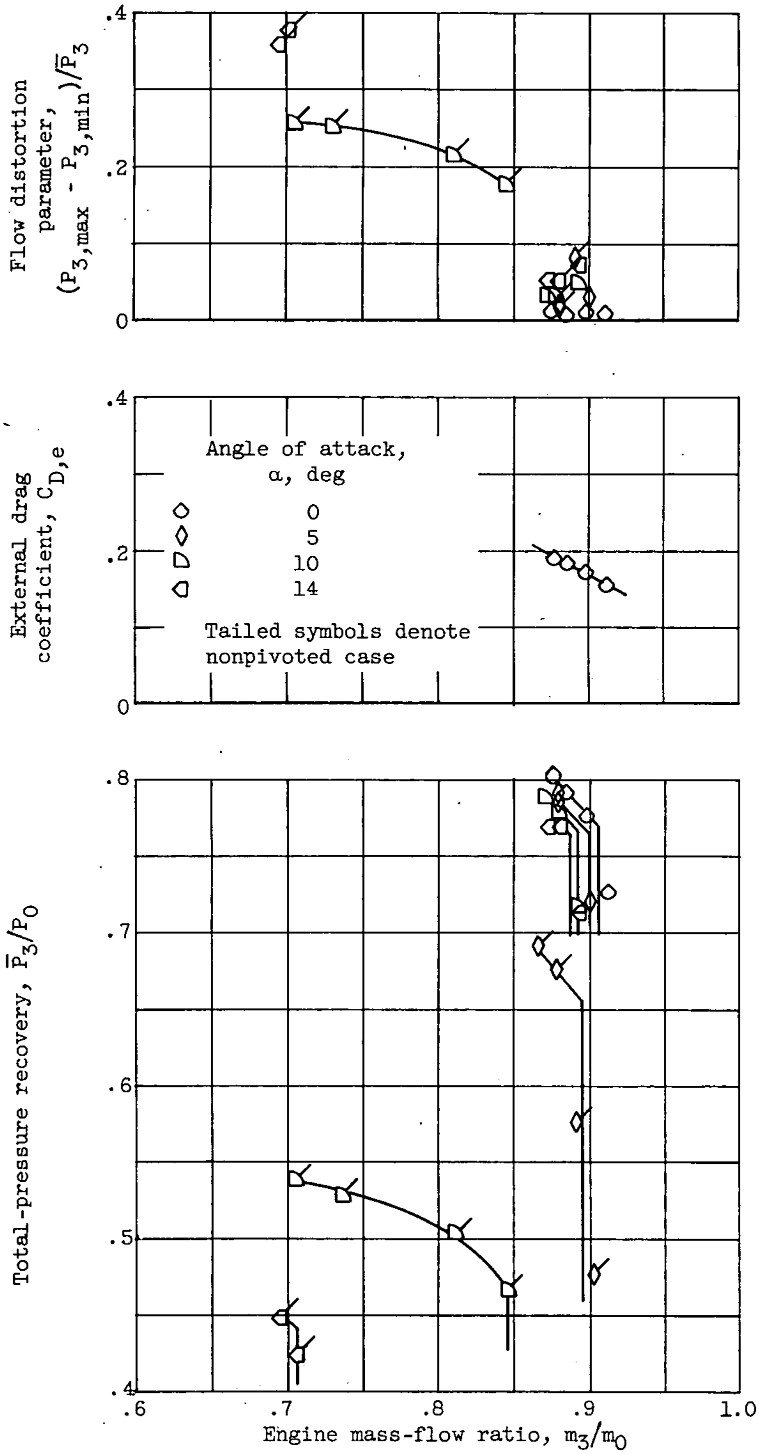
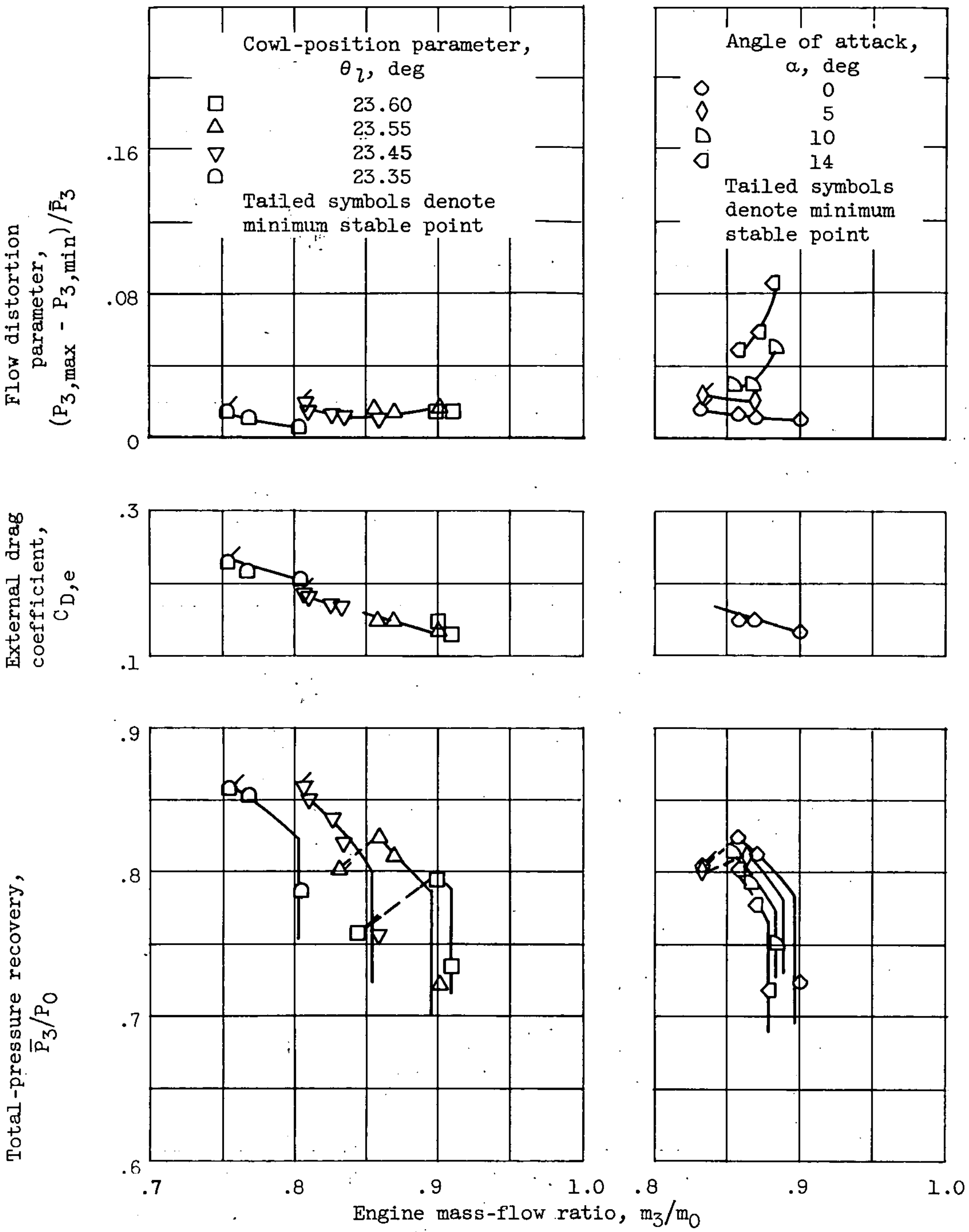


Figure 7. - Effect of angle of attack on performance of 35° compression spike configuration with and without inlet-spike pivoting at a free-stream Mach number of 3.0 and a cowl-position parameter of 23.60°.



(a) Varying cowl-position parameter at zero angle of attack.

(b) Cowl-position parameter, 23.55°; angles of attack, 0°, 5°, 10°, and 14°; inlet spike pivoted.

Figure 8. - Effect of cowl-position parameter and angle of attack on performance of 39° compression spike inlet at free-stream Mach number of 3.0.

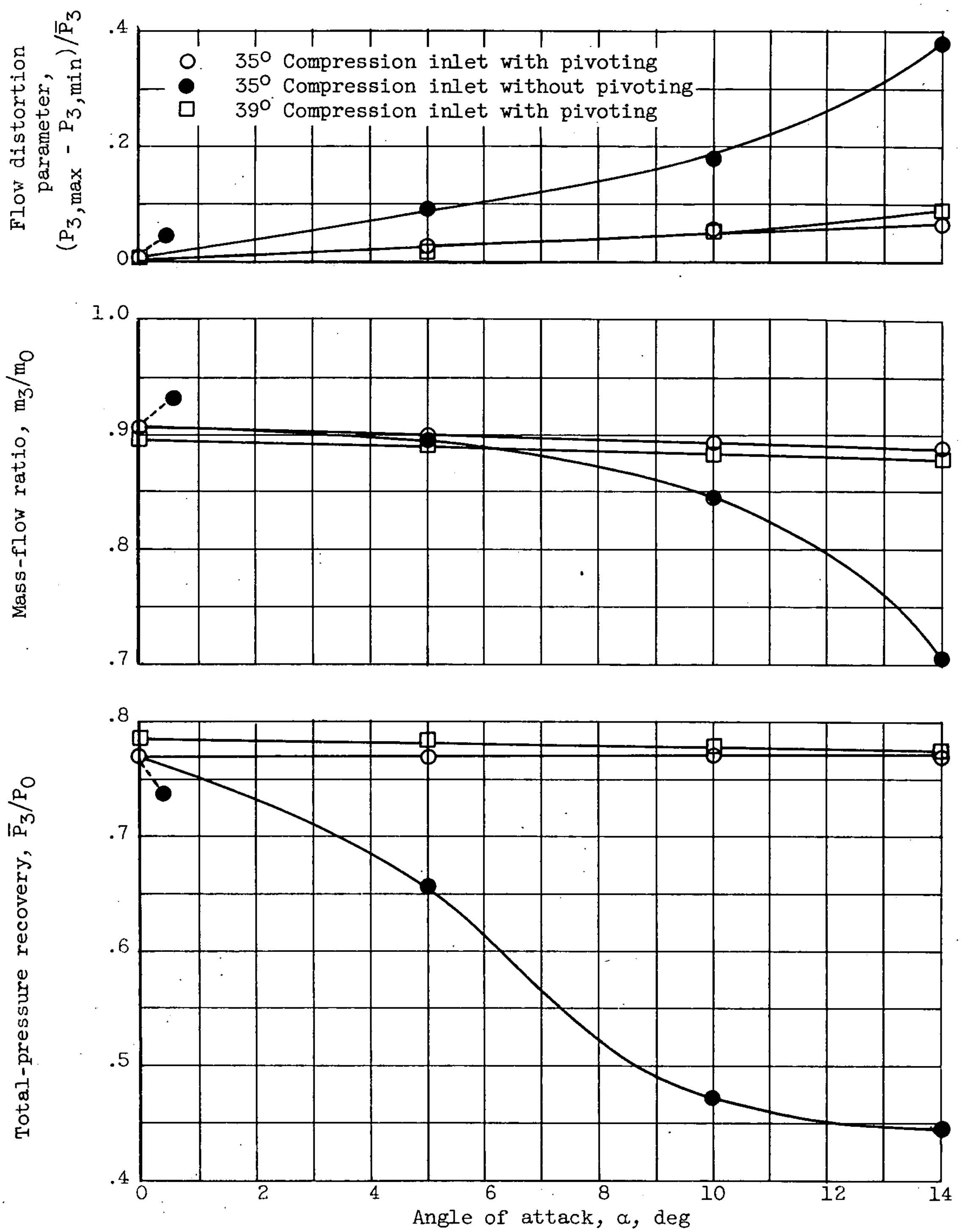
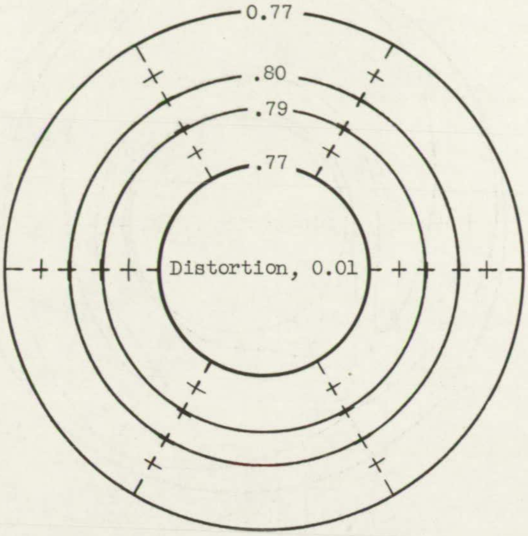
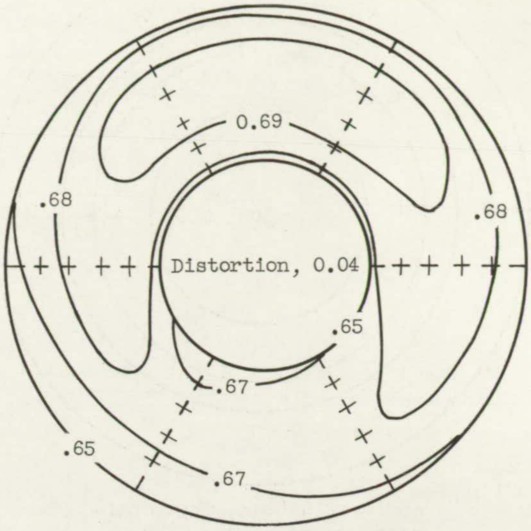


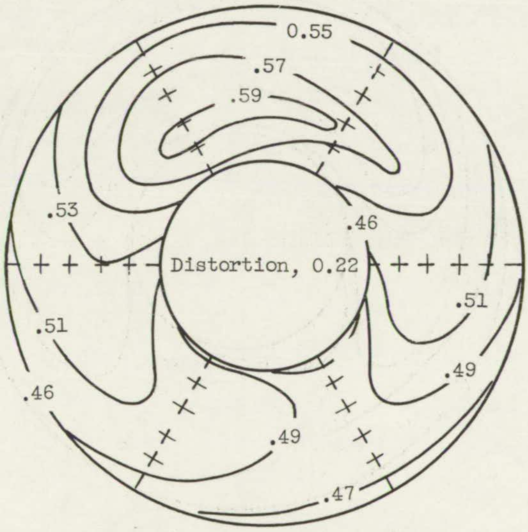
Figure 9. - Effect of angle of attack on performance with and without inlet pivoting during critical Mach 3.0 operation.



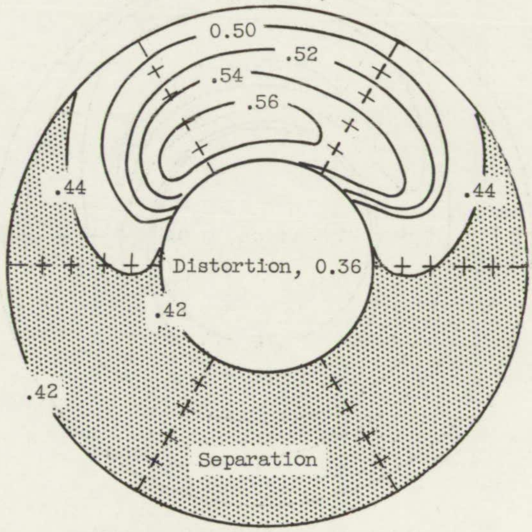
Angle of attack, 0°; total-pressure recovery, 0.79



Angle of attack, 5°; total-pressure recovery, 0.68



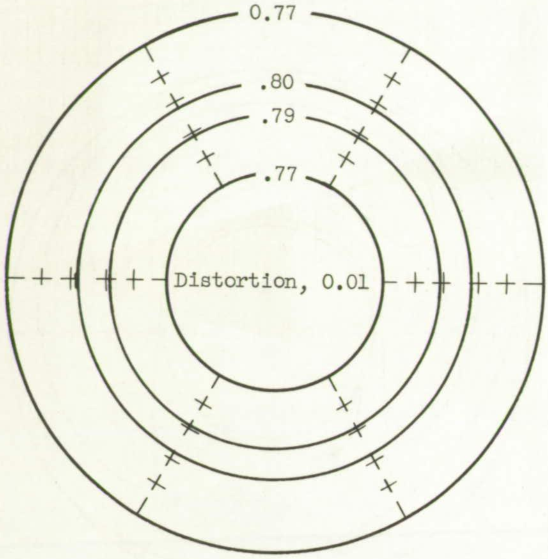
Angle of attack, 10°; total-pressure recovery, 0.51



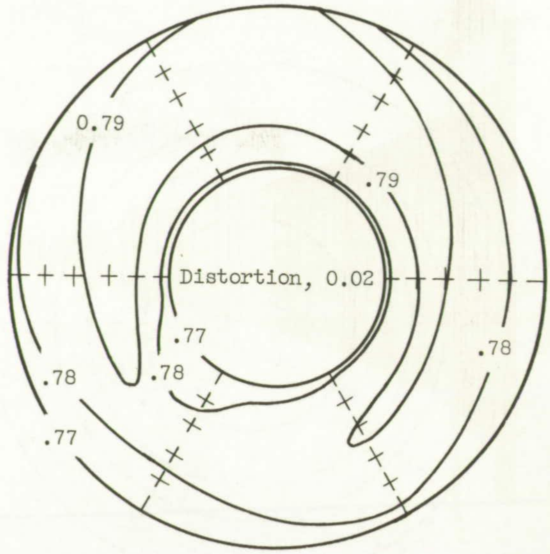
Angle of attack, 14°; total-pressure recovery, 0.45

(a) Without pivoting.

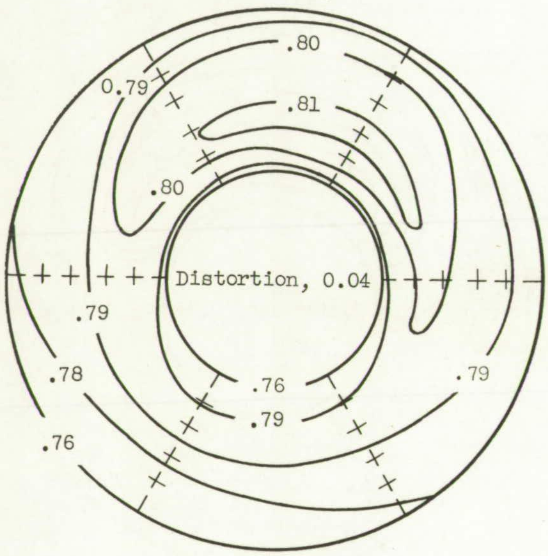
Figure 10. - Total-pressure contours at diffuser exit for near critical operation for 35° compression inlet with and without pivoting at free-stream Mach number of 3.0.



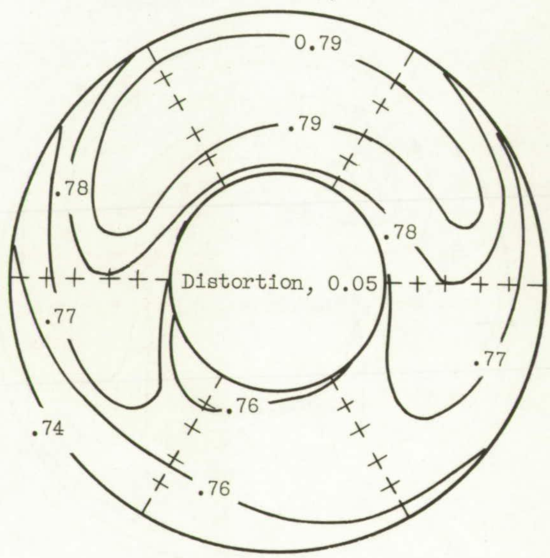
Angle of attack, 0°; total-pressure recovery, 0.79



Angle of attack, 5°; total-pressure recovery, 0.79



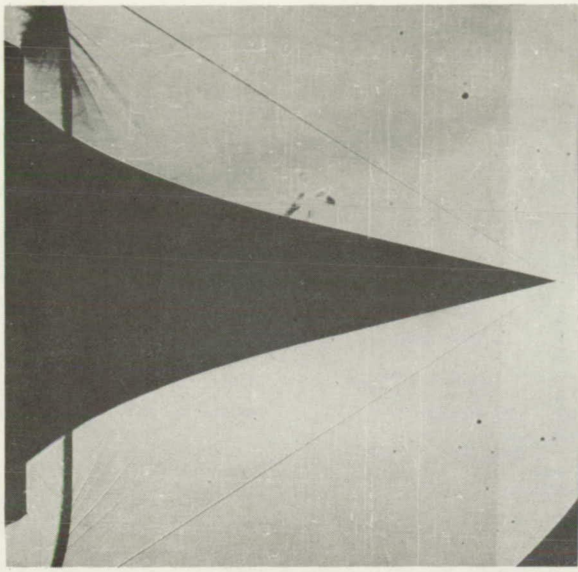
Angle of attack, 10°; total-pressure recovery, 0.79



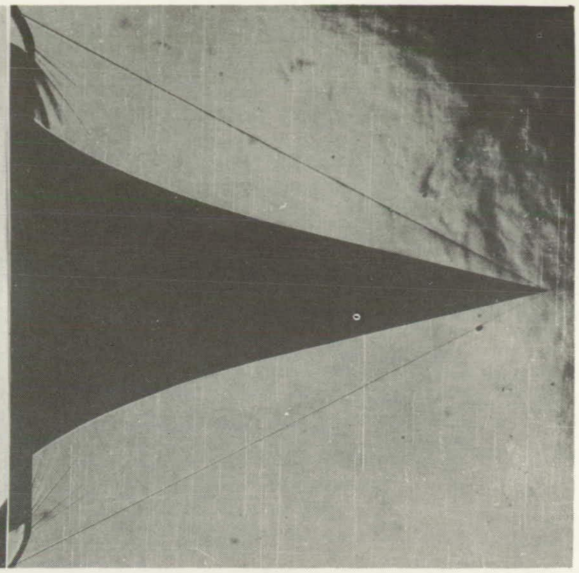
Angle of attack, 14°, total-pressure recovery, 0.77

(b) With pivoting.

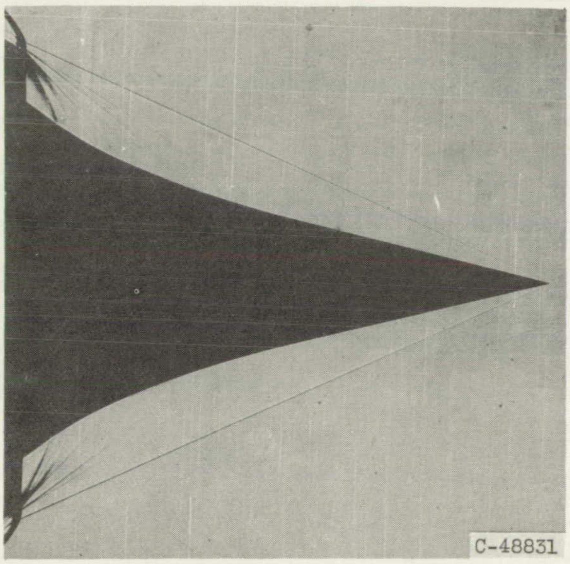
Figure 10. - Concluded. Total-pressure contours at diffuser exit for near critical operation for 35° compression inlet with and without pivoting at free-stream Mach number of 3.0.



Free-stream Mach number, 2.0



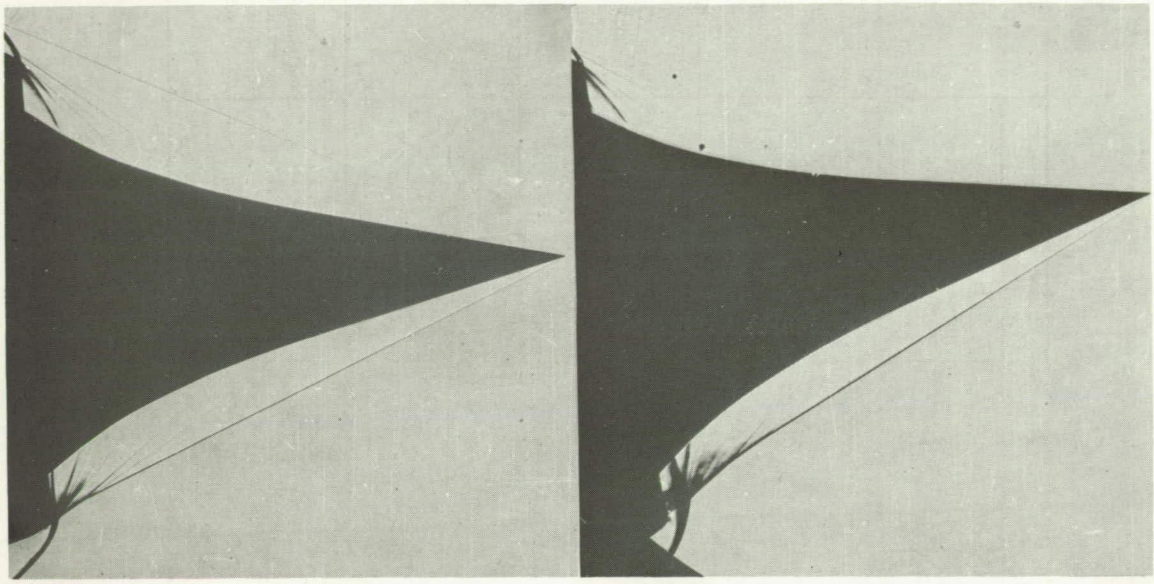
Free-stream Mach number, 2.5



Free-stream Mach number, 3.0

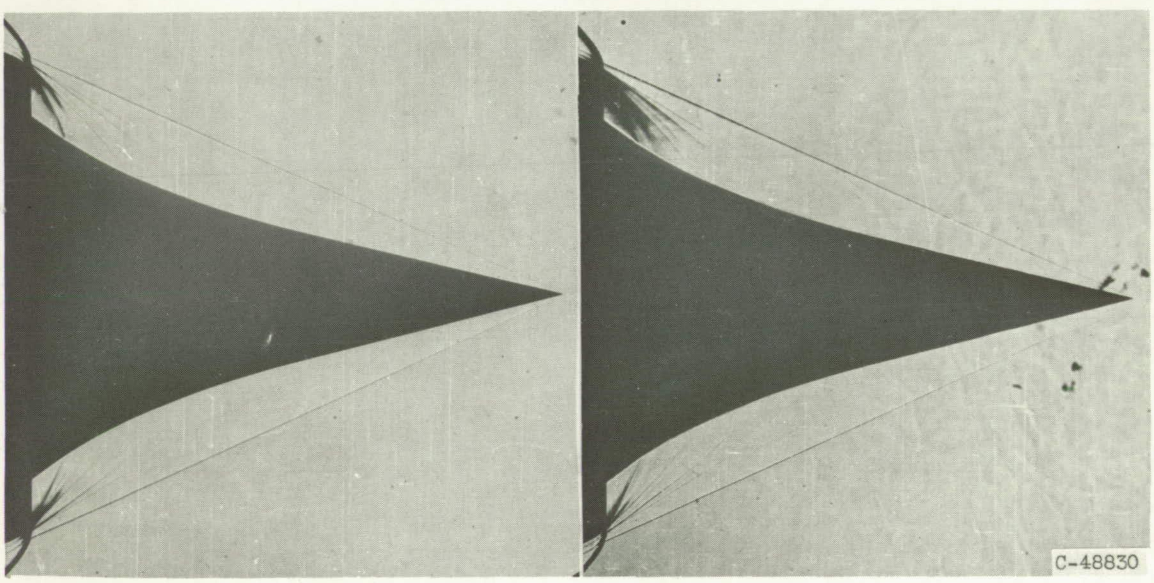
(a) Inlet operated supercritically at zero angle of attack over Mach number range investigated.

Figure 11. - Schlieren photographs of 35° compression spike inlet.



Angle of attack, 5°; unpivoted

Angle of attack, 10°; unpivoted



Angle of attack, 5°; pivoted

Angle of attack, 10°; pivoted

(b) Inlet operated with and without inlet pivoting at several angles of attack. Free-stream Mach number, 3.0.

Figure 11. - Concluded. Schlieren photographs of 35° compression spike inlet.

NACA - Langley Field, Va.

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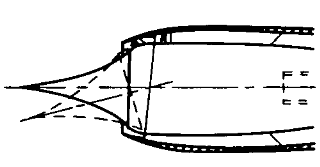
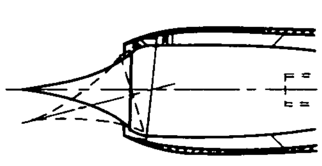
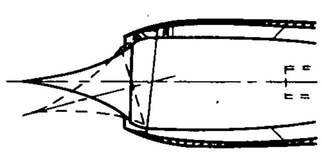
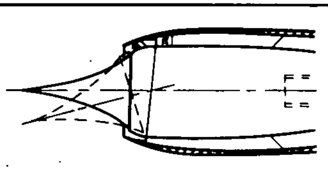
NOTES: (1) Reynolds number is based on the diameter of a circle with the same area as that of the capture area of the inlet.

(2) The symbol * denotes the occurrence of buzz.

INLET BIBLIOGRAPHY SHEET

Report and facility	Description			Test parameters				Test data				Performance		Remarks
	Configuration	Number of oblique shocks	Type of boundary-layer control	Free-stream Mach number	Reynolds number $\times 10^{-6}$	Angle of attack, deg	Angle of yaw, deg	Drag	Inlet-flow profile	Discharge-flow profile	Flow picture	Maximum total-pressure recovery	Mass-flow ratio	
CONFID. RM E58G11a 10- by 10-ft supersonic wind tunnel		Isentropic	Ram scoop	2.0 to 3.0	2.89	0 to 14	0	√		√	√	0.86	0.39* to 0.92	A pivoting cowl and spike technique for efficient angle-of-attack operation of supersonic inlets has been investigated for its effectiveness.
CONFID. RM E58G11a 10- by 10-ft supersonic wind tunnel		Isentropic	Ram scoop	2.0 to 3.0	2.89	0 to 14	0	√		√	√	0.86	0.39* to 0.92	A pivoting cowl and spike technique for efficient angle-of-attack operation of supersonic inlets has been investigated for its effectiveness.
CONFID. RM E58G11a 10- by 10-ft supersonic wind tunnel		Isentropic	Ram scoop	2.0 to 3.0	2.89	0 to 14	0	√		√	√	0.86	0.39* to 0.92	A pivoting cowl and spike technique for efficient angle-of-attack operation of supersonic inlets has been investigated for its effectiveness.
CONFID. RM E58G11a 10- by 10-ft supersonic wind tunnel		Isentropic	Ram scoop	2.0 to 3.0	2.89	0 to 14	0	√		√	√	0.86	0.39* to 0.92	A pivoting cowl and spike technique for efficient angle-of-attack operation of supersonic inlets has been investigated for its effectiveness.

Bibliography

These strips are provided for the convenience of the reader and can be removed from this report to compile a bibliography of NACA inlet reports. This page is being added only to inlet reports and is on a trial basis.

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